1. NAME OF INITIATIVE: LHC CMS Detector Upgrade Initiative

List of major collaborating institutions (including non-US partners).
The US CMS Collaboration

2. SCIENTIFIC JUSTIFICATION:

Physics goals. How does it fit into the global physics goals for the entire field.
The LHC is anticipated to start operation in April 2007, initially at low instantaneous luminosity. During the operation of the LHC, the instantaneous luminosity will increase until it reaches the design luminosity of 10^{34} $cm^{-2}sec^{-1}$. After running the CMS experiment for several years in this mode, it will be unprofitable to continue operation of the experiment unless there is an upgrade in the luminosity of the LHC. Figure 1 illustrates this situation.

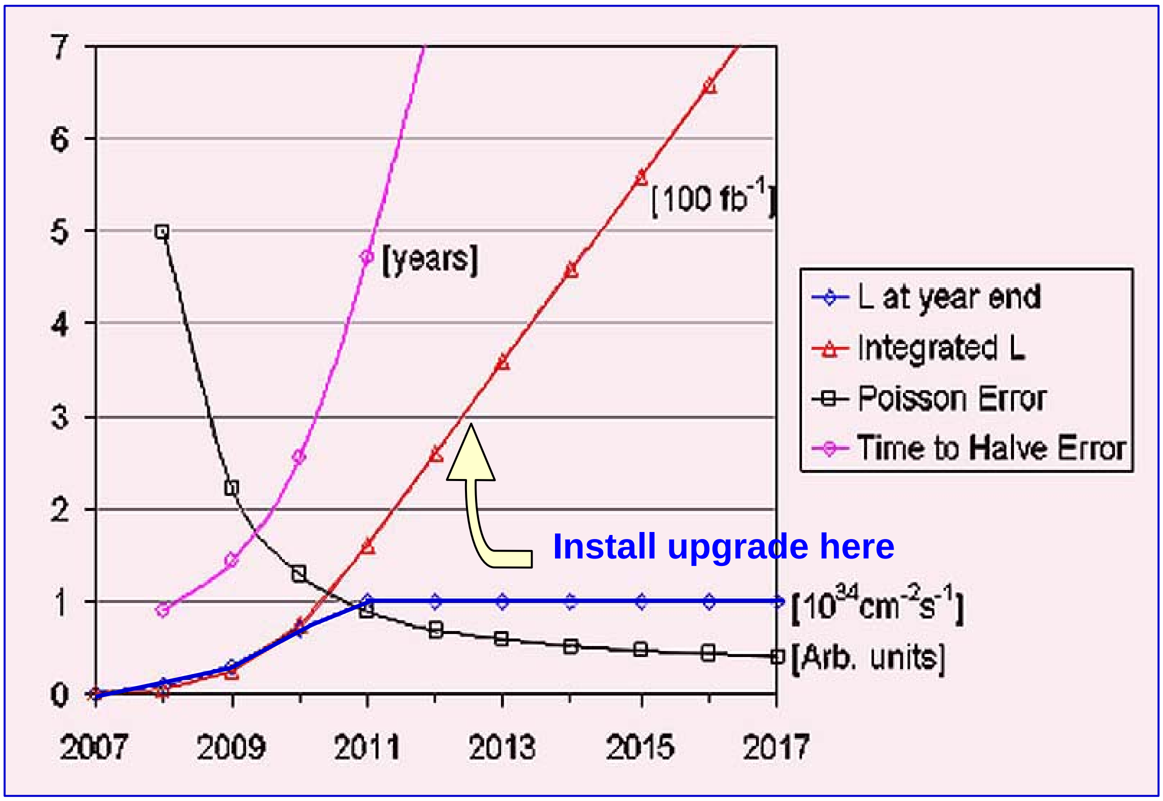

Figure 1. LHC luminosity, integrated luminosity, statistical error, and years of additional operation required to divide the statistical error by 2 vs. calendar year. (figure courtesy Jim Strait.)

The blue curve in Figure 1 shows a hypothetical instantaneous luminosity growth for the LHC. The red curve shows the corresponding integrated luminosity. The black curve shows the statistical error of an arbitrary measurement in arbitrary units. The magenta curve shows the halving time of that statistical error in years of additional operation. We see that soon after the nominal luminosity of the LHC is reached, there is little benefit in continued operation without a luminosity upgrade of the LHC. This luminosity upgrade, known as the SLHC, is expected to happen around 2013. It is planned to be a factor of 10 upgrade to an instantaneous luminosity of 10^{35} $cm^{-2}sec^{-1}$.

Features of the SLHC upgrade are the factor of 10 increase in luminosity and a factor of 2 decrease in bunch spacing from 25 ns to 12.5ns. The expected radiation dose of the CMS detector during SLHC operation will be 10X more than that of the LHC operation. Table 1 shows a summary of relevant differences between LHC and SLHC.

	LHC	**SLHC**
$\sqrt{s}$	14 TeV	14 TeV
L	10^{34}	10^{35}
	100	1000
Bunch spacing dt	25 ns	12.5 ns
N. interactions/x-ing	~ 20	~ 100
dNch/dη per x-ing	~ 75	~ 375
Tracker occupancy	1	5
Pile-up noise	1	~2.2
Dose central region	1	10

Table 1. Parameters of LHC and SLHC.

We see from Table 1 that the number of minimum-bias events per crossing will increase to about 60 causing a factor of 5 increase in tracker occupancy under the assumption that the tracker can distinguish events separated by 12.5ns. The radiation dose will also increase by a factor of 10, as indicated above. These two effects will have a severe impact on the CMS central tracker. It will have to be completely replaced for the SLHC. Technologies (pixel or strip) that work at a given radius at the LHC will have to be moved out about a factor of 3 in radius to preserve the same radiation dose and occupancy at the SLHC. A totally new technology will be needed at the innermost radius.

The CMS hadron calorimeter between eta of 1.5 and 3 will suffer enough radiation damage to make it inoperable. Existing scintillator cannot withstand the increased radiation levels of the SLHC so this part of the calorimeter will need to be replaced with a new technology.

The forward muon system will need to complete it's coverage at high eta. Although there are no conceptual problems with building the chambers, a vendor will need to be found for the G-10 honeycomb plates.

The Level-1 trigger will need to be replaced for operation at the SLHC. The present design study involves use of tracking information in the level-1 trigger with new calorimeter and muon trigger processors interfaced to tracking correlation systems. The level-1 global trigger and trigger signal distribution systems will also need to be replaced. All parts of the DAQ system will either need replacement or upgrades to function at the SLHC as well.

The electromagnetic calorimeter is expected to remain functional at the SLHC, although with increased occupancy.

3. VALIDATIONS FOR SCIENTIFIC JUSTIFICATION:

Examples of recommendations and supporting statements from the committees, panels, and the community at large.
CERN has reviewed the idea of the SLHC and the associated upgrades and approved it. The US part of SLHC detector R&D (as I describe in the note) has been reviewed and approved by a joint NSF/DOE review.

4. DESIRED SCHEDULE:

List major milestones (month & year) such as design complete, construction start, construction complete, etc.
The SLHC upgrade is anticipated for the year 2013. Silicon tracking detectors require 3-4 years for construction so all R&D and design should be ready by 2009. The hadron calorimeter active element fabrication takes about 2 to 3 years, so we should be ready to start this by 2010 – 2011. A replacement trigger should be ready on the same timescale.

5. ROUGH COST ESTIMATE:

Whatever the best information available (eg. $M +/-30~50%, $150~250M, etc.). Total cost range including non-DOE funding (if any other funding sources are assumed and if known, state from where and how much. Also indicate remaining R&D cost to go.
Because the upgrade ideas are tentative, cost estimates shown below are for illustrative purposes only.

Tracker replacement $100M.
Endcap muon chambers and trigger $5M
Upgrade to the trigger and DAQ $10M
Hadron active element replacement $2M.

The costs of these replacements will be born by the entire CMS community, with the US CMS collaboration covering some fraction.

6. DESIRED NEAR TERM R&D:

Major activities needed to be completed before start construction.

The US CMS collaboration has a limited budget for R&D that is used to fund small activities. We are concentrating our R&D activities on parts of the CMS detector that we have had an historical responsibility for.

We are currently studying possible active element replacements for the hadron calorimeter. These include Cerenkov plates and new scintillators. In addition we are studying red-sensitive photodetectors which may play a role in the upgrade.

We are pursuing several R&D studies for the replacement tracker. We are just starting study of a new silicon material, magnetic CZ silicon, for possible use in the central tracker. Other possible materials, for instance diamond, are also under consideration. We are studying the use of amorphous silicon for ASIC production in a pixel detector. A new tracker will have many more readout channels that the current one. Low cost data links are being studied for this application.

We are searching for new vendors for materials needed for extension of the endcap muon eta coverage. We are doing conceptual design studies for muon trigger upgrades that incorporate enhanced forward coverage.

A joint tracker and trigger design study has been initiated. We are working on new designs of the calorimeter and muon trigger systems that will interface to tracking trigger information at level-1.

R&D will continue on the more fruitful options with the goal of making major impacts in the design of these future detectors.

7. BRIEF DESCRIPTION OF LABORATORY’S ANTICIPATED ROLE:

Expected unique capabilities to be provided by lab. Rough estimate of human resources from lab (#FTE in what type labor).

Fermilab is foreseen to play an active role in DAQ enhancements, hadron calorimeter upgrades, muon chamber fabrication, and silicon tracker developments.

The Lab 8 facility allows parts for large muon chambers to be machined. These parts will be assembled by technicians in Technical Division. 15 FTE are needed for a three year period 2009 – 2012.

DAQ and trigger development will continue at a low rate between now and the SLHC, with a constant level of about 3 FTE of scientists and computer professionals..

The hadron calorimeter R&D and construction will require a low rate of less than 1 FTE involvement.

A unique asset of Fermilab is SiDet. We expect that SiDet will play a major role in construction of the new CMS tracker. The exact level of participation will be the outcome of CMS-wide planning and the availability of funding. A possible level is 20 FTE of technicians between 2008 and 2012.